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EXPERIMENTAL INVESTIGATION & FUZZY LOGIC MODELLING OF HEAT TRANSFER ENHANCEMENT FOR WAVY TWISTED TAPE INSERT

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ABSTRACT
The present work shows the results obtained from experimental investigations of the augmentation of turbulent flow heat transfer in a horizontal tube by means of wavy twisted tape inserts with air as the working fluid. Experiments were carried out for plain tube with/without wavy twisted tape insert at constant wall heat flux and different mass flow rates. The wavy twisted tapes are of same wave-width, but three different twist ratios as 8.33, 9.79 & 10.42. The Reynolds number varied from 4000 to 9500. Both heat transfer coefficient and pressure drop are calculated and the results are compared with those of plain tube. It was found that the enhancement of heat transfer with wavy twisted tape inserts as compared to plain tube varied from 17% to 45 % for various inserts. Also the results are compared with the plane twisted tape insert. The experimental results of heat transfer in circular tube equipped with the different inserts is studied using a fuzzy inference system named Mamdani and used to expect the output membership functions be fuzzy sets. The inputs to the fuzzy inference system are Reynolds No, No of twists in inserts, Temperature and the output of the system Nusselt No & friction factor.

KEYWORDS: Enhancement efficiency, turbulent, Wavy twisted tape insert, Heat transfer Enhancement, wave-width, twist ratio .

INTRODUCTION

Heat Transfer Enhancement

Heat exchangers have several industrial and engineering applications. The designing of heat exchangers is quite complicated, as it needs correct analysis of heat transfer rate and pressure drop estimations apart from issues such as long-term performance and the economic aspect of the equipment. The major challenge in designing a heat exchanger is to make the equipment compact and achieve a high heat transfer rate using minimum pumping power. Techniques for heat transfer augmentation are relevant to several engineering applications. In recent years, the high cost of energy and material has resulted in an increased effort aimed at producing more efficient heat exchange equipment. Furthermore, sometimes there is a need for miniaturization of a heat exchanger in specific applications, such as space application, through an augmentation of heat transfer. For example, a heat exchanger for an ocean thermal energy conversion (OTEC) plant requires a heat transfer surface area of the order of 10000 m^2/MW. Therefore, an increase in the efficiency of the heat exchanger through an augmentation technique may result in a considerable saving in the material cost. Furthermore, as a heat exchanger becomes older, the resistance to heat transfer increases owing to fouling or scaling. These problems are more common for heat exchangers used in marine applications and in chemical industries. In some specific applications, such as heat exchangers dealing with fluids of low thermal conductivity (gases and oils) and desalination plants, there is a need to increase the heat transfer rate. The heat transfer rate can be improved by introducing a disturbance in the fluid flow (breaking the viscous and thermal boundary layers), but in the process pumping power may increase significantly and ultimately the pumping cost becomes high. Therefore, to achieve a desired heat transfer rate in an existing heat exchanger at an economic pumping power, several techniques have been proposed in recent years and are discussed in the following sections.

Fuzzy Logic

Fuzzy logic is a method which can be used to model the experiments, and it has been introduced for the first time in 1965 by Zadeh . Modeling of experiments can be helpful to reduce its costs. By using the models, we can predict results of experiments, which have not performed, or are not possible to perform due to some restrictions. In this study, the fuzzy logic methodology has been used in order to model and predict the experimental results. A simple fuzzy consists from four major parts: Fuzzification interface, Fuzzy rule base, Fuzzy inference engine, and defuzzification interface. A fuzzification operator has the effect of transforming crisp data into fuzzy sets. A fuzzy rule represents a fuzzy relation between two fuzzy sets. It takes a form such as; *if x is A then y is B*. Each fuzzy set is characterized by suitable membership functions. A fuzzy rule base contains a set of fuzzy rules, where each rule may have multiple inputs and multiple outputs. Fuzzy inferencing can be realized by utilizing a set of fuzzy operations. The defuzzification interface mixes and converts fuzzy membership functions into significant numerical outputs. Depending on the types of inference operations upon *if-then* rules, two types of fuzzy inference systems have been widely employed in various applications such as automatic control, data classification, decision analysis, expert systems, and computer vision: Mamdani fuzzy models and Sugeno fuzzy models, which is similar to the Mamdani model in many respects. The first two parts of the fuzzy inference process, fuzzifying the inputs and applying the fuzzy operator, are exactly the same. The main difference between Mamdani and Sugeno is that the Sugeno output membership functions are either linear or constant . The fuzzy system which has been used here is Mamdani which is the most commonly seen fuzzy methodology

EXPERIMENTAL SET UP

The schematic diagram of experimental set-up is given in Figure 1.

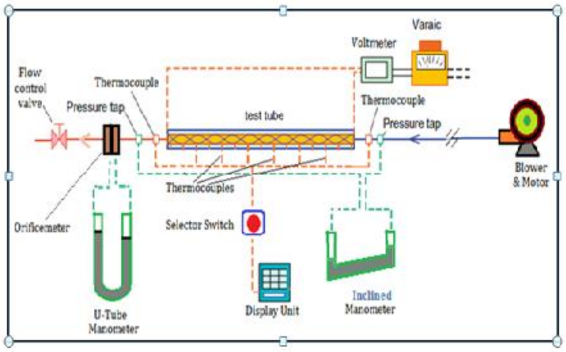


Fig-1*:* Experimental setup of Forced Convection .

The experimental facility includes a blower, an orifice meter to measure the volumetric flow rate, the heat transfer test tube (700 mm) . The MS test tube 26 mm inner diameter (D_1), 26.4 mm outer diameter (D_2), and 2 mm thickness (t). The wavy twisted tapes are tested in this experiment, with three different twist ratios as 8.33, 9.79 & 10.42 but have same wave-width as 13mm. They are fabricated from aluminium. Also one plane twisted tape made up of aluminium is tested. The schematic figure of the test tube with wavy twisted tape insert is given in Figure 2.

Fig- 2: Schematic of test tube with wavy tape inserted

The wavy twisted tapes contained in the experimental study are shown in Figure 3.

Fig-3: Actual view of wavy twisted tape inserts

A 0.24 hp blower is used to force air through the test tube. Uniform heat flux is applied to external surface of the test tube by means of heating with electrical winding, whose output power is controlled by a variac transformer to supply constant heat flux along the entire section of the test tube. The outer surface of the test tube is well insulated with glass wool to reduce the convective heat loss to the surroundings. The external surface emperatures of the test tube wall are measured by 6 K-type thermocouples, which are placed on the outer wall of the test tube. Also, the inlet and outlet temperatures of the bulk air are measured by two K-type thermocouples at given points. An inclined manometer is used to measure pressure drop across the test tube. After air passes the test tube, it enters to the orifice meter for determining volumetric flow rate readings. For this purpose a separate U-tube manometer is placed across orifice meter. The volumetric flow rate of air supplied from the blower is controlled by varying control valve position. The experiments are conducted by varying the flow rate in terms of Reynolds numbers from 4181 to 9466 of the bulk air. The test tube is heated from the external surface during the experiments, and the data of temperatures, volumetric flow rate, pressure drop of the bulk air and electrical output are recorded after the system is approached to the steady state condition. The Nusselt number, Reynolds number, friction factor, heat transfer enhancement are calculated based on the average outer wall temperatures and the inlet and outlet air temperatures.

DATA COLLECTION AND ANALYSIS

The data reduction of the obtained results is summarized in the following procedures:

3.1. Heat Transfer Calculations

$T_s= (T_2+T_3+T_4+T_5+T_6+T_7)/6$ (1)

$T_b= (T_1+T_8)/2$ (2)

Equivalent height of air column,= $(\rho_w * h_w)/\rho_a$ (3)

Discharge of air, Q_a=Cd *Ao (4)

Velocity of air flow, V= Q_a /A (5)

Reynolds number, Re=V D/ν (6)

$Q = *C_p*(T_8-T_1) \quad \sqrt{2*g*h_{air}}$ (7)

$$h = \frac{Q}{A(T_s - T_b)} \quad (8)$$

$$Nu = \frac{hD}{k} \quad (9)$$

$$f = \frac{\Delta P}{\frac{L}{D}\cdot\frac{\rho_a V^2}{2}} \quad (10)$$

$$\eta = \frac{(Nu_t/Nu)}{(f_t/f)^{0.333}} \quad (11)$$

VALIDATION EXPERIMENTS OF PLAIN TUBE

In this study, experimental results of Nusselt number and friction factor for the plain tube are obtained and validated with equations of Dittus Boelter and Petukhov as given below;

$$Nu_{th} = 0.023 Re^{0.8} \; Pr^{0.4} \qquad (12)$$

$$f_{th} = (1.82 * \log_{10} Re - 1.64)^{-2} \qquad (13)$$

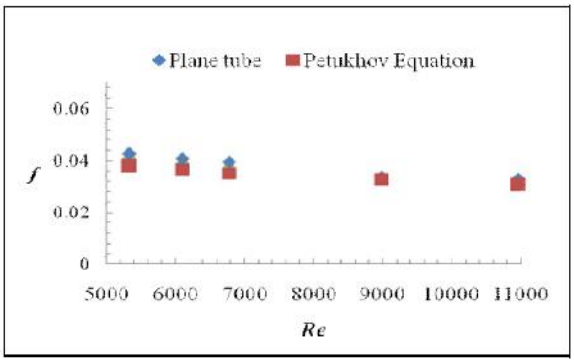


Fig-4: Validation results for friction factor

The comparisons of Nusselt number and friction factor for the present plain tube with existing correlations are shown in Figs. 4 and 5, respectively. These figures shows that validation experiments of heat transfer in terms of Nusselt number and friction factor for the plain tube are in good agreement with the results obtained from Dittus-Boelter and Petukhov equations. The results of present plain tube and previous equations are nearly the aame. Thus, this accuracy provides reliable results for heat transfer and friction factor in a tube with twisted tape inserts in this present study.

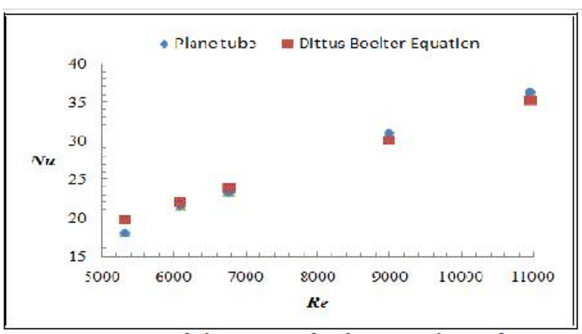


Fig- 5: Validation results for Nusselt number

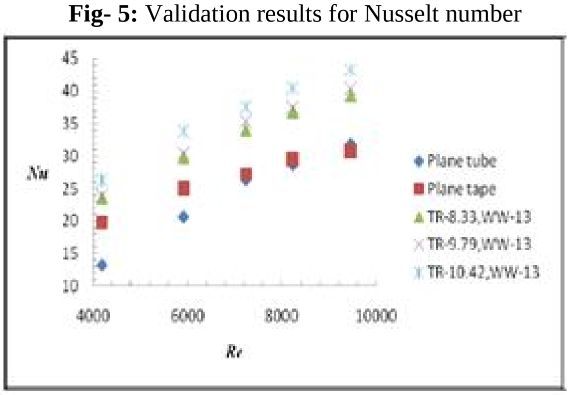


Fig-6: Variation of Nusselt number for different insert configurations

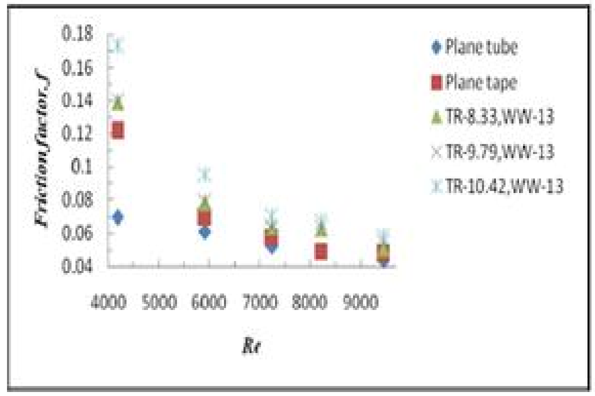


Fig-7: Variation of friction factor for different insert configurations

RESULTS AND DISCUSSION

Heat Transfer and Overall Enhancement Characteristics

The variation of Nusselt number with Reynolds number for various wavy inserts is shown in Figure 6. Highest Nusselt number was obtained for tape with twist ratio of 10.42. The Nusselt number for wavy inserts varied from 35% to 77% compared to plain tube. This is due to strong turbulence intensity generated by corrugations on inserts leading to rapid mixing of the flow causing heat transfer enhancement. The variations of friction factor with Reynolds number for wavy tape inserts are presented in Figure 7. It is observed that the friction factor gradually reduced with rise in Reynolds number. It is observed to be maximum, for insert having twist ratio of 10.42. It is evident from Figures 6, 7 and 8 that when a wavy twisted tape is inserted into a plain tube there is a significant improvement in Nusselt number because of secondary flow, with greater enhancement being realized at lower Reynolds numbers and higher twist ratio keeping wave-width same.

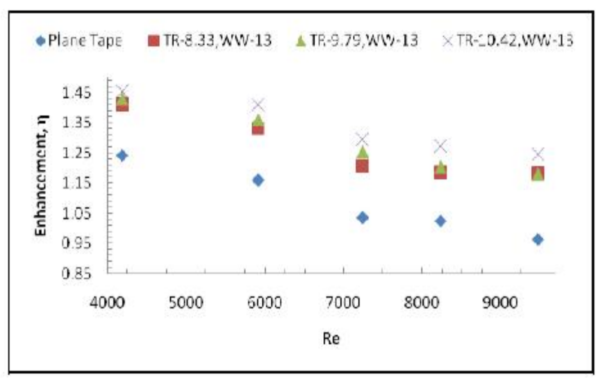
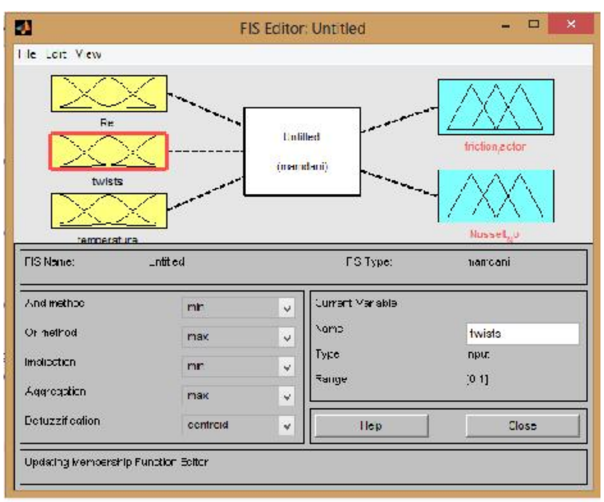


Fig 8: Variation of Enhancement for different insert configurations

This enhancement is mainly due to the centrifugal forces resulting from the spiral motion of the fluid and partly due to the tape acting as fin. It is observed that the rise in twist ratio causes increment in Nusselt numbers as well as rise in pressure drop. From Figure 6, the percentage rise in Nusselt numbers for wavy twisted tapes compared to plain tube are about 23-77%, 26-79% and 35-97% respectively for tape with twist ratio 8.33,9.79 & 10.42 respectively keeping wave-widths same as 13mm.The overall enhancement ratio is useful to evaluate the quality of heat transfer enhancement obtained over plain tube at constant pumping power. It is found to be more than unity for all the wavy twisted tape inserts used. Variations of overall enhancement ratio η against Reynolds number for various tapes are shown in figure 8. It is observed that overall enhancement tended to decrease gradually with the rise of Reynolds number for all twist ratios. The maximum value of overall enhancement is 1.45 for wavy twisted tape insert having wave-width of 13mm with twist ratio 10.42. It is seen in figure 8 that, for tapes of twist ratios 8.33, 9.79 & 10.42 curves are of decreasing order for a given wave-width in the range of Reynolds number from 4100 to 9400.

FUZZY LOGIC MODELLING

The aim of this Fuzzy logic is to consider the effect of two main factors, Reynolds number , Number of twists and the surface temperature of the tube through which the heat exchanges. In order to perform fuzzy logic, input and output variables and their levels must be determined. Reynolds number (Re) in 3 levels ranging from 4500 to 9000, temperature in three levels from 320 K to 330 K, Number of twists from 8.33 to 10.5, as input variables and friction factor , Nusslet No as output variable were chosen. The Mamdani inference system used in this study is shown in Figure. 9. Symmetric triangular membership functions for output and input variables were defined. Figures 10, show membership functions for input variables, i.e. Reynolds number, and temperature. The membership functions of friction factor and Nusslet No. are brought in Figure 11. Some parts of rules, which were chosen for the fuzzy model, are shown in Fig 4.4 & Fig. 4.7. Therefore experimental results are modeled by fuzzy interference system, which shows that, the fuzzy logic is a reliable method to model & predict the heat transfer coefficient. According to fuzzy logic, with increasing Reynolds number, the heat transfer coefficient increases. This result may be explained by the generation of stronger turbulence intensity and more rapid mixing of flow created by twisted wire insert



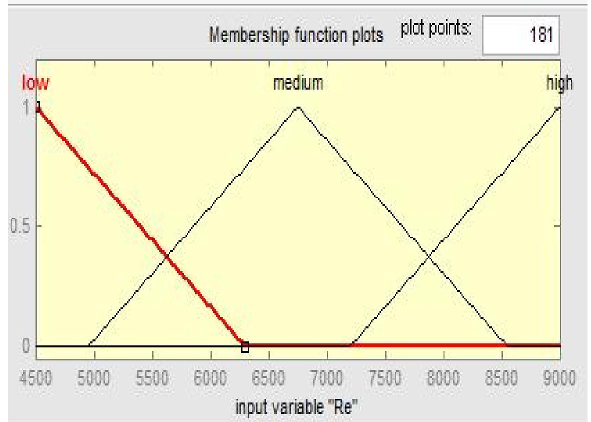


Fig- 9 Mamdani system used entire system and member function for Re

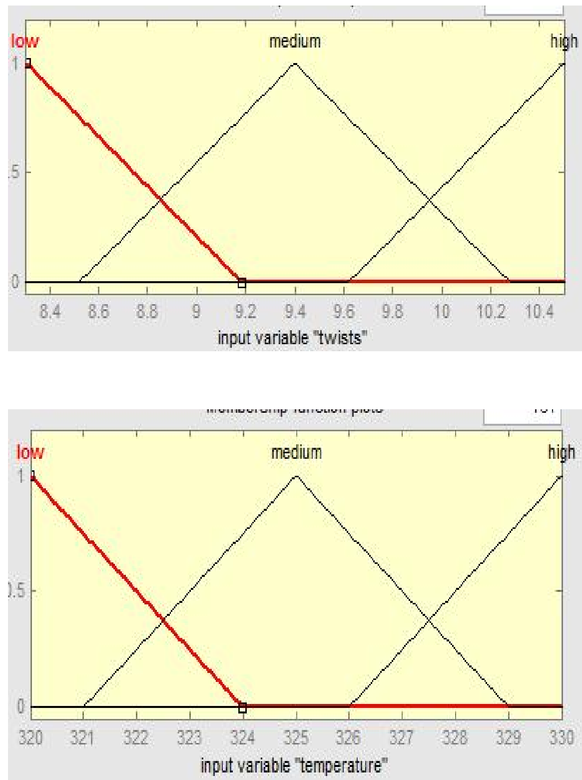
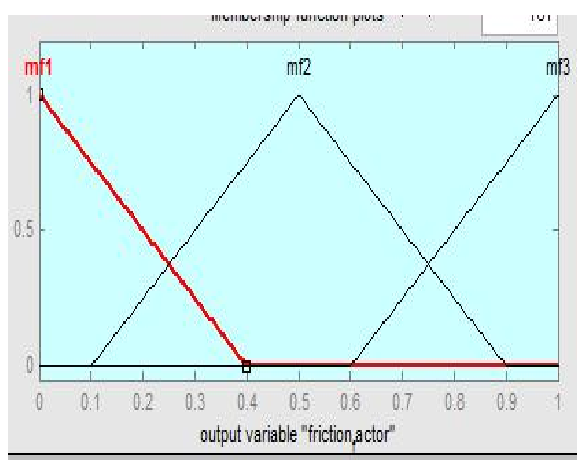


Fig-10. Member function for twists and temperature



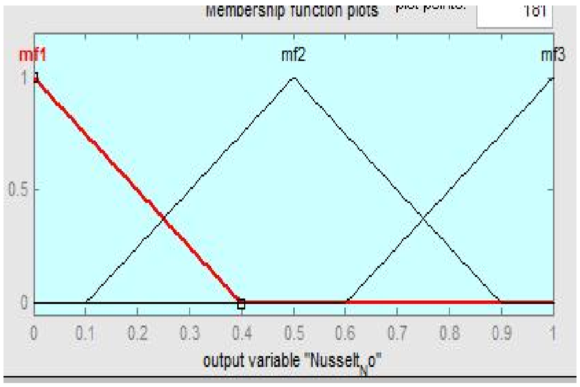


Fig-11. Member function for output friction factor and Nusselt No.

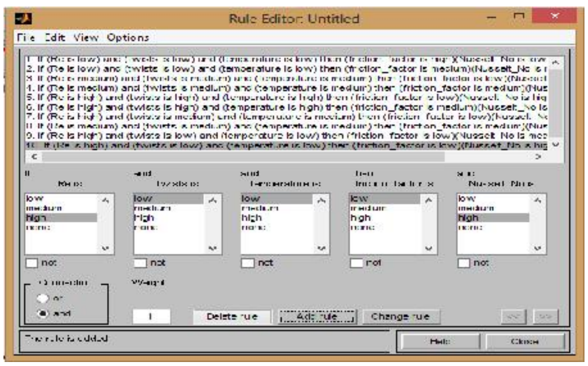


Fig 12. Rule Editor Window

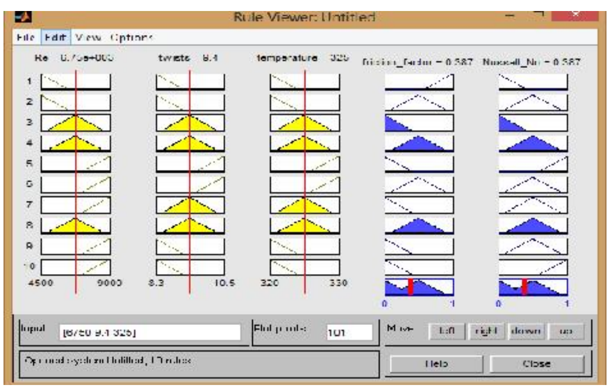


Fig 13. Rule Viewer Window

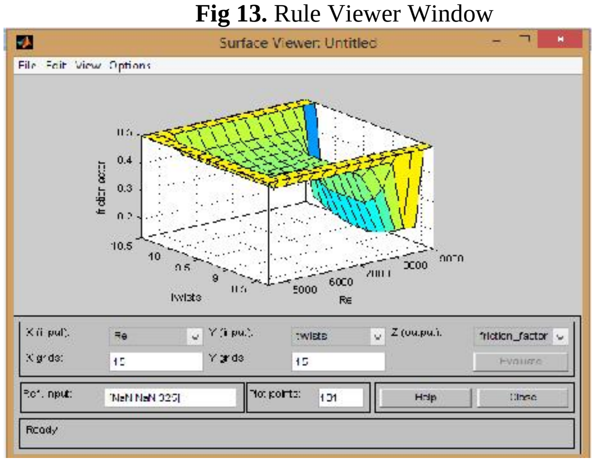


Fig. 14. Input Vairable Reynolds number , twists and with output variable friction factor

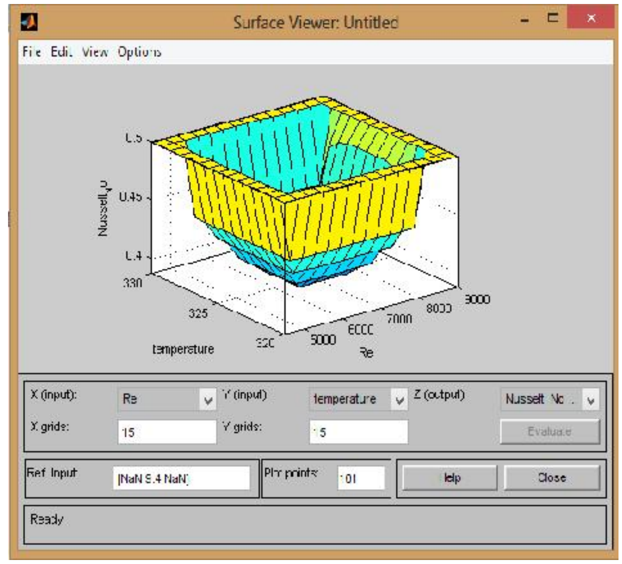


Fig- 15. Input Vairable Reynolds number , temperaturfe and with output variable Nu

CONCLUSIONS

The study presents an experimental investigation of the potential of wavy twisted tape inserts to enhance the rate of heat transfer in a horizontal circular tube with inside diameter 26 mm with air as working fluid. The Reynolds number varied from 4100 to 9400. The effects of parameters such as modified twist ratio, Reynolds number on the heat transfer and overall enhancement ratio are studied.

The modelling of experimental results of heat transfer from an Heat Exchanger equipped with twisted tape insert, placed in a pipe, was studied by the use of fuzzy logic. This method was used to gain relationship between three input parameters namely Reynolds number , number of twists and temperature, and the friction factor , Nusselt number as output variable.The following conclusions can be drawn.

1. The enhancement of heat transfer with wavy twisted tape inserts as compared to plain tube varied from 17 to 40% for twist ratio 8.33 and from 24 to 45% for twist ratio of 10.42. This enhancement is mainly due to the centrifugal forces resulting from the spiral motion of the fluid. Rise in twist ratio causes rise in Nusselt numbers as well as friction factors.

2. The maximum friction factor rise was about 100% for twist ratio 8.33 and 150% for twist ratio 10.42 for wavy twisted tape inserts compared to plain tube.

3. The overall enhancement for the tubes with wavy twisted tape inserts is 1.40 for twist ratio 8.33 and 1.45 for twist ratio 10.42 for wavy twisted tape insert.

4. Thus the enhanced performance can be achieved using wavy twisted tapes as compared to plane twisted tape. Thus, from the considerations of enhanced heat transfer and savings in pumping power wavy-width tape inserts are seen to be attractive for enhancing turbulent flow heat transfer in a horizontal circular tube.

REFERENCES

1. Hsieh and Huang , “Experimental studies for heat transfer and pressure drop of laminar flow in horizontal tubes with/without longitudinal inserts” 2000.,

2. Sarma, “Heat transfer coefficients with twisted tape inserts”, 2003.

3. Hsieh, “Experimental studies on heat transfer and flow characteristics for turbulent flow of air in a horizontal circular tube with strip type insert”, 2003.

4. Pairson Naphon ,“Effect of coil-wire insert on heat transfer enhancement and pressure drop of the horizontal concentric tube”, International Communications in Heat and Mass Transfer 33 (2006) 753–763,2006.

5. Smith Eiamsa-ard , Pongjet Promvonge,“ Heat transfer characteristics in a tube fitted with helical screw-tape with/without core-rod inserts”, International Communications in Heat and Mass Transfer 34 (2007) 176–185.

6. Monheit. M, 1987,” Experimental evaluation of the convective characteristics of tubes with twisted tape inserts”, Advances in Enhanced Heat Transfer, AMSE, New York, pp. 11–18.

7. Dasmahapatra J. K, and Raja Rao M, “ Laminar Flow heat transfer to generalized power law fluids inside circular tubes fitted with regularly spaced twisted tape elements for uniform wall temperature condition”, Fundamentals of Heat Transfer in Non- Newtonian Fluids, ASME, New York, pp. 51–58.

8. Al-Fahed S, and Chakroun W, 1996, “Effect of tube -tape clearance on heat transfer for fully developed turbulent flow in a horizontal isothermal tube”, Int. J. Heat Fluid Flow, Vol. 17, No. 2, pp. 173-178.

9. Manglik R.M and Bergles A.E, 1992, “Heat transfer enhancement and pressure drop in viscous liquid flows in isothermal tubes with twisted-tape inserts”, Heat and Mass Transfer, Vol. 27, No. 4, pp. 249-257

10. Manglik R.M and Bergles A.E, “Application of twisted tape inserts in tubular heat exchangers” , Heat and Mass Transfer, Vol. 27, No. 4, pp. 249-257.

11. Chang S.W, Yang T.L, Liou J.S, 2007. “Heat transfer and pressure drop in tube with broken twisted tape insert”, Experimental Thermal and Fluid Science, Vol. 32, No. 2, pp. 489–501.

12. Saha S.K and Mallick D. N., September 2005. “Heat transfer and pressure drop characteristics of laminar flow in rectangular and square plain ducts and ducts with twisted-tape inserts”, Transactions of the ASME, Vol. 127.

13. L.A. Zadeh, “Fuzzy sets,” Information Control, vol.8, pp.338-353, 1965.

14. K. Belarbi, F. Titel, W. Bourebia, K. Benmahammed, “Design of Mamdani Fuzzy logic controllers with rule base minimisation using genetic algorithm,” Engineering Applications of Artificial Intelligence, vol.18, pp.875-880, 2005.

15. M. Sugeno, Industrial Applications of Fuzzy control, Amsterdam, Elsevier, 1985.